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UNDISCOVERED NATURAL GAS RESOURCES OF MONTANA

Maher Ibrahim

July 15, 1976

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A list of all those who provided assistance would be incomplete no matter how thorough or long it would be written. For this reason, the author of the report would like to request each and every one who helped in writing this report to consider this as an individual "thank you."

However, it would be appropriate to mention the special aid given by the Resource Appraisal Group of the U.S. Geologic Survey in Denver, Montana Bureau of Mines and Geology, Montana Oil and Gas Division of the Department of National Resources and Conservation, and Montana Energy Advisory Council Staff and Coordinator.

Particular appreciation is extended to the members of the Steering Committee and their representing organizations. Names of the members of the Steering Committee are given on a separate page.

List of Members of the Steering Committee

Mr. Don Allen
Montana Petroleum Association

Mr. Roger Billings
Vice President
Montana Power Company

Mr. Larry Geske
Executive Vice President
Great Falls Gas Company

Mr. Allen Griffith
Montana Power Company

Mr. Jay Johnson
Montana Power Company

Mr. Charles Maio
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Oil Resources, Inc.

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Energy Research Coordinator
MEAC

Mr. Robert Rhodes
Montana Power Company

Dr. Arnold Silverman
Geology Department
University of Montana

Mr. Judson Sweet
Oil and Gas Division
Department of Natural Resources
& Conservation

The July meeting in Billings was attended, in addition to members from the Steering Committee, by:

Mr. Tom Frizzell
Montana Environmental Quality Council

Mr. Dan Potts
Hoerner-Waldrof Corporation

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INTRODUCTION

The Montana Energy Advisory Council (MEAC), in its effort to develop a comprehensive state energy policy, has been particularly interested in the future supply of energy resources for the State of Montana. This report is a part of Montana Cooperative Agreement Number CA-05-60763-00, with the Federal Energy Administration (FEA) for the Northern Tier study. It includes an investigation of the undiscovered natural gas resources of Montana in the light of announced Canadian curtailment of refinery feedstocks to Montana.

A Steering Committee was selected for the guidance and orientation of the project. The criteria for selecting the committee was to have a wide spectrum of representation of persons knowledgeable in the gas business. A quick look at the list of members of the committee shows the representation of the governmental organizations, gas industry, and academic institutions. Meetings of the Steering Committee have been open to persons interested in the area of the study. In addition to this wide spectrum of representation of expertise reflected in the structure of the Steering Committee, the principle investigator has established a wide range of personal contacts with organizations and persons working in the same field of study.

The first meeting of the Steering Committee was held June 8, 1976, in Butte, Montana. At this meeting the project outline was developed for this short duration study. It was suggested to restrict the study to determining estimates of the undiscovered natural gas resources in Montana. These were computed mainly with the application of the techniques used by: (a) the U.S. Geological Survey (RAG) Resource Appraisal Group, and (b) the Potential Gas Committee of the Colorado School of Mines.

Contacts were established with representatives of both organizations by the principle investigator for acquiring the data for the project.

The second Steering Committee meeting was held July 12, 1976, in Billings, Montana. The Committee discussed the results presented by the principle investigator and made their comments and modifications to the resource figures as estimated using the two previously mentioned methods.

Following that meeting, it was clear that further contacts with the Resource Appraisal Group in Denver were needed to get an in-depth understanding of their resource estimates for certain particular basins.

The principle investigator met with members of the Resources Appraisal Group in Denver for that purpose and contacted the Wyoming Geological Survey in Laramie, Wyoming, with regard to Wyoming resources estimates for the basins shared between Wyoming and Montana.

ABSTRACT

The undiscovered recoverable natural gas resources of Montana are the focus of this report. This study shows, using data from the Resource Appraisal Group of the U.S. Geological Survey, that in addition to approximately 930 billion cubic feet (BCF) of proved gas reserves in Montana (1975 AGA), there are at least two trillion cubic feet of gas in the undiscovered and inferred resource categories. This amount of gas would provide Montana an equivalent of 37 years of natural gas supply at the 1974 level of consumption of about 81 BCF.

The most optimistic estimate for the potential natural gas resources of Montana was suggested by the project Steering Committee as 7.06 trillion cubic feet of gas. This would provide about 87 years of supply of natural gas at the 1974 level. Other estimates of natural gas resources in Montana are given in this report which are intermediate to these two extremes. Most of the difference in estimates lies in the estimated gas resources of the Montana Folded Belt, particularly the "Overthrust Belt". The existence of a giant gas field in this area of the size of the Canadian Pincher Creek Gas Field is not excluded. Such a discovery, could ensure Montana gas supply for at least twenty years.

The future of Montana's gas supply looks bright even under lowest resource estimate. Discoveries of new gas fields in the most speculative areas would need a more aggressive exploration and development policy to overcome complex geological structures, expensive deep wells, and, if permitted, the strict regulations of drilling in National Parks or wilderness areas.

ABBREVIATIONS

U.S.G.S.	United States Geological Survey
RAG	Resource Appraisal Group of the U.S.G.S.
API	American Petroleum Institute
AGA	American Gas Association
MEAC	Montana Energy Advisory Council
USBM	United States Bureau of Mines

TERMINOLOGY
(USED BY THE RESOURCE APPRAISAL GROUP OF THE U.S.G.S.)

The following are some of the terms used and illustrated by the attached Figure 1. Further detailed information needed is available in U.S. Geological Survey Circular 725. In these definitions, price-cost relationships and technological trends prevailing in the recent years prior to 1974 are assumed.

Resources - Concentrations of naturally occurring solid, liquid, or gaseous materials in or on Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.

Identified Resources - Specific accumulations of economic resources whose location, quality, and quantity are estimated from geologic evidence supported in part by engineering measurements.

Undiscovered Resources - Quantities of a resource estimated to exist outside of known fields on the basis of broad geologic knowledge and theory.

Undiscovered Recoverable Resources - Those economic resources, yet undiscovered, which are estimated to exist in favorable geologic setting.

Reserves - That portion of the Identified Resource which can be economically extracted.

Measured Reserves - That part of the identified resource which can be economically extracted using existing technology, and whose amount is estimated from geologic evidence supported directly by engineering measurements. They are considered to be equivalent to API and AGA Proved Reserves.

Indicated Reserves - Reserves that include additional recoveries in known reservoirs (in excess of the Measured Reserves) which engineering knowledge and judgment indicate will be economically available by application of fluid injection, whether or not such a program is currently installed. The Indicated Reserves are equivalent to API Indicated Additional Reserves.

Demonstrated Reserves - A collective term for the sum of Measured and Indicated Reserves.

Inferred Reserves - Reserves in addition to Demonstrated Reserves eventually to be added to known fields through extensions, revisions, and new pays.

Comparison of the terminology used by the RAG and others is given in Figure 2.

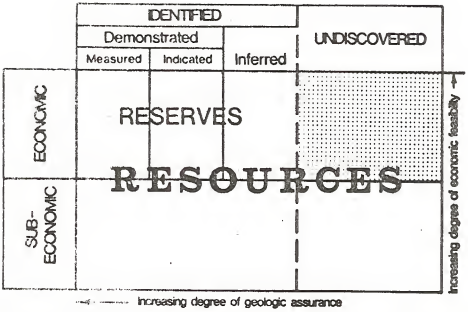


FIGURE 1 —Diagrammatic representation of petroleum resource classification by the U.S. Geological Survey and the U.S. Bureau of Mines (modified from McKelvey, 1973).

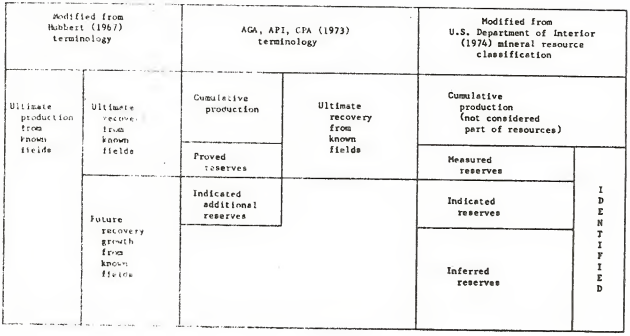


FIGURE 2.—Correlation of production and reserve terminology.

TERMINOLOGY

Used by the Potential Gas Committee

The following is a copy of the definitions of the specific terms used by the Potential Gas Committee in their publications.

1. DEFINITION OF NATURAL GAS

Natural gas, as used in this report, is any gas of natural origin that is composed primarily of hydrocarbon molecules producible from a borehole. Most natural gas contains some nonhydrocarbon components such as carbon dioxide, nitrogen, hydrogen sulfide, helium, etc.; however, in estimating potential supply, it is not feasible to separate small volumes of these components from the hydrocarbons. Areas or formations that are believed to contain large volumes of such nonhydrocarbon components are not counted as potential supply.

2. DEFINITION OF POTENTIAL GAS

The phrase "potential supply of natural gas" as used by the Potential Gas Committee in making its estimates and in preparing its report, means: At a given date and underlying a particular geographic area, that prospective quantity of natural gas yet to be found and proved (as the term *proved* is used by the American Gas Association Committee of Natural Gas Reserves) by all wells which may be drilled in the future under assumed conditions of adequate but reasonable prices and normal improvements in technology.

The definition of *potential supply* specifies a relationship to proved reserves because the Committee's estimate at any given date is not to include any proved reserves existing as of that date but is to include such volumes as may become proved reserves in the future. Potential supply is a volume of gas which is in addition to existing proved reserves. An estimate of potential supply must take into consideration the criteria used by the Committee on Natural Gas Reserves of the American Gas Association in preparing its annual estimates of proved recoverable reserves. The Committee on Natural Gas Reserves defines proved recoverable reserves* as follows:

> The current estimated quantity of natural gas and natural gas liquids which analysis of geologic and engineering data demonstrate with reasonable certainty to be recoverable in the future from known oil and gas reservoirs under existing economic and operating conditions. Reservoirs are considered proved that have demonstrated the ability to produce by either actual production or conclusive formation test.
>
> The area of a reservoir considered proved is that portion delineated by drilling and defined by gas-oil, gas-water contacts or limited by structural deformation or lenticularity of the reservoir. In the absence of fluid contacts, the lowest known structural occurrence of hydrocarbons controls the proved limits of the reservoir. The proved area of a reservoir may also include the adjoining portions not delineated by drilling but which can be evaluated as economically productive on the basis of geological and engineering data available at the time the estimate is made. Therefore, the reserves reported by the Committee include total proved reserves which may be in either the drilled or the undrilled portions of the field or reservoir.

The Committee on Natural Gas Reserves includes in proved reserves all gas estimated to be producible from tested formations under existing operating and economic conditions without regard to the size, use, or disposition of any production. Proved reserves in an undrilled area, however, must be so related to the developed or tested leases and to known field geology that its productive ability is assured.

3. CATEGORIES OF POTENTIAL GAS SUPPLY

Accuracy of the estimates of gas volumes included in the potential supply of a given area are dependent upon geological conditions and the extent to which the area has been explored and developed. Using available geologic data and the American Association of Petroleum Geologists classification of wells (fig. 5), the Work Committee divides the estimates into three broad categories. These categories are as follows:

a. Probable potential gas supply (associated with existing fields).
   (1) Supply from known accumulations obtained by:
      (a) Future extensions of *existing pools*, in known productive reservoirs.
      (b) Future *new pool* discoveries, within existing fields, in reservoirs productive elsewhere within the same field.
   (2) Supply from *new pool* discoveries obtained by:
      (a) Future shallower and/or deeper new pool discoveries, within existing fields, in formations productive elsewhere within the same geologic province or sub-province, under *similar* geologic conditions.

*A.G.A. Proved Reserves Report, v. 27, p. 102, May 1973.

(b) Future shallower and/or deeper new pool discoveries, within existing fields, in formations productive elsewhere within the same geologic province or sub-province, under *different* geological conditions.

b. Possible potential gas supply (associated with productive formations).

(1) Supply from *new field* discoveries obtained by:

(a) Future new field discoveries, in formations *productive* elsewhere within the same geologic province or sub-province, under *similar* geological conditions.

(b) Future new field discoveries, in formations *productive* elsewhere within the same geologic province or sub-province, under *different* geological conditions.

c. Speculative potential gas supply (associated with non-productive formations)

(1) Supply from *new pool* discoveries in formations not previously productive within a productive geologic province or sub-province.

(2) Supply from *new field* discoveries obtained by:

(a) Future new field discoveries in formations *not previously productive* within a productive geologic province or sub-province.

(b) Future new field discoveries within a geologic province *not previously productive*.

A *geologic province* is defined in *Glossary of Geology and Related Sciences*, by the American Geological Institute, as "A large area or region unified in some way and considered as a whole." Hence, the Gulf Coast geosyncline and the Appalachian geosyncline often are referred to as *provinces*. Large provinces, such as those cited, are often divided into sub-provinces to recognize geological homogeneity. Examples of sub-provinces are the Mississippi embayment of the Gulf Coast geosyncline (province) and the Delaware basin within the Permian basin (province).

The term *basin* is avoided in the Guidelines, except in the preceding illustrations, because it has topographic and geomorphic meanings, as well as geologic. These meanings are often different and can lead to misinterpretations.

It is evident from the above that, as drilling progresses, gas volumes estimated to be in a particular reservoir will move from one category to another as shown schematically in figure 6. Since any projection of potential supply lacks the accuracy of the proved reserve figures, particularly in the speculative category, it must be recognized that these estimates of potential supply will also be subject to upward and downward revisions when new geological and engineering data are provided by exploratory drilling. When gas is finally classified in the *Proved* category, it will no longer be included in the estimated potential supply.

CLASSIFICATION OF WELLS

DRILLING OBJECTIVE			ILLUSTR.	INITIAL WELL CLASSIFICATION	FINAL WELL CLASSIFICATION	
					SUCCESSFUL	UNSUCCESSFUL
EXPLOITATION OF ACCUMULATION DISCOVERED BY PREVIOUS DRILLING			1	DEVELOPMENT	DEVELOPMENT	DRY DEVELOPMENT
LONG EXTENSION OF PARTLY DEVELOPED POOL			2	OUTPOST OR EXTENSION	EXTENSION (SOMETIMES NEW-POOL DISCOVERY WELL)	DRY EXTENSION
NEW POOL ON STRUCTURE/ENVIRONMENT ALREADY PRODUCTIVE	WITHIN LIMITS OF PROVEN POOL	ABOVE DEEPEST PROVEN POOL	3	SHALLOWER POOL	SHALLOWER POOL DISCOVERY	DRY SHALLOWER POOL
		BELOW DEEPEST PROVEN POOL	4	DEEPER POOL	DEEPER POOL DISCOVERY	DRY DEEPER POOL
	OUTSIDE LIMITS OF PROVEN POOL		5	NEW POOL WILDCAT	NEW POOL DISCOVERY (SOMETIMES EXTENSION WELL)	DRY NEW POOL
NEW FIELD ON STRUCTURE/ENVIRONMENT NEVER BEFORE PRODUCTIVE			6	NEW FIELD WILDCAT	NEW FIELD DISCOVERY	DRY NEW FIELD WILDCAT

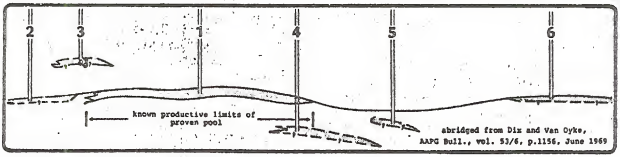


FIGURE 5.

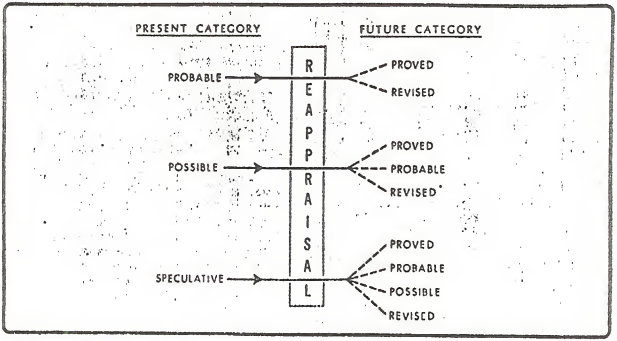


FIGURE 6 — Flow chart illustrating progression of Potential Gas Supplies as a result of Drilling.

Regions and Areas

The different groups working on resource appraisal usually divide the nation into several regions or areas including several states or parts of states. Montana is always selected as a part of the Northern Rocky Mountain Area or Region regardless of the boundaries of such unit. The published estimates for undiscovered gas are given to the Northern Rockies as a whole. In this report we isolated Montana resources of natural gas from the rest of the Northern Rocky Mountain Area. This section of the report will deal with a brief review of the methodology of the different groups, followed by the procedure used to segregate Montana's resources. Figures 3 and 4 show the regional boundaries and work areas as used by the U.S. Geological Survey Resource Appraisal Group and the Potential Gas Committee, respectively.

BASIC RESOURCE APPRAISAL METHODS

There are different techniques which could be used by estimating hydrocarbon potential of a specific area. The process of selecting a method or methods to estimate the petroleum potential of a certain region is of extreme importance to obtain relevant results. Resource estimates practiced recently fall into three categories:(1)

I - Historic Performance Extrapolation Methods

This first category uses the technique of fitting the past performance with mathematical model to establish a growth curve which could be expanded in the future. The following are some of the criteria which could be used for this performance matching technique:

(a) discovery rate,
(b) cumulative production, or
(c) productive capacity.

The techniques of this category are most applicable in later stages of exploration (mature areas).

II - Volumetric - Yield Methods

The simplest of these methods is assuming an average yield in cubic feet of gas per cubic mile of sedimentary rock volume or per square mile of surface area. This average yield would be applied evenly over a widely distributed sedimentary rock area. A more advanced approach is using what is called analogus basin yield factors for application in specific areas. Such analogus yield factors need careful study and comparison of geology of the province under study and the province for which such factors would be applied.

(1) U.S.G.S. Circular 725

III - Composite Methods - Geological and Statistical Probabilistic Models

These methods are more complicated and sophisticated and need wide range of information to be handled by mathematical computer models. These models may involve, in addition to geologic basin evaluation studies: play analysis, economic, decision making and comprehensive geological analog models. The high sophistication of these methods is not associated by high accuracy. Subjective judgment by the investigators is always needed.

U.S. GEOLOGIC SURVEY METHODOLOGY

The definitions of special terms used by this group are given in the terminology. The resource appraisal techniques used by this group are diversified and depend on the availability of geologic information for each province. The main methods used, as given in their report, are:

(1) An extrapolation of known producibility into untested sediments of similar geology for a well developed area;

(2) Volumetric techniques using geologic analogs and setting upper and lower yield limits through comparisons with a number of known areas;

(3) Volumetric estimates with an arbitrary general yield factor applied when direct analogs were unknown;

(4) Hendricks' (1965)[1] potential area; and,

(5) Comprehensive comparisons of all known published estimates for each area to all estimates generated by the above methods.

Detailed explanation of the appraisal procedure is given in U.S. Geological Survey Circular 725.

The representative of each region, through comprehensive comparison of the collected geological information, estimates subjective probability figures for the occurrence of oil and gas in commercial quantities. The following are the estimates:

(1) A low resource estimate corresponding to 95 percent probability that there is at Least that amount.

(2) A high resource estimate with a 5 percent probability that there is at Least that amount.

---

[1] See References

(3) A model estimate of resource which the estimator associates with the highest probability of occurrence that there will be that amount.

(4) A statistical mean which is calculated by adding the low value, the high value, and the model value, and dividing the sum by three.

In a meeting between the Resource Appraisal Group and the representatives of the provinces, a final review of the data and the estimates is made.

Following the detailed reviews, each member of the Committee and appropriate representatives and area experts individually make their resource appraisal estimates for the province by the subjective probability procedures described in the previous section:

(a) A low estimate with 95 percent probability;
(b) A high estimate with 5 percent probability;
(c) A model estimate with the highest probability; and,
(d) A calculated statistical mean.

From the individual evaluators' estimates, the group resolved the differences and a group concensus was arrived at for a range of estimates as defined in (a) through (d).

These Resource Appraisal Group estimates were then fed back to the respective representatives and U.S. Geologic Survey geologists doing the initial geology for each province. In case of difference of opinion between RAG estimates and original geologists' evaluations, the process was recycled and analyzed to resolve the difference.

The final figures thus obtained were analyzed statistically using the Monte Carlo simulation procedures, and was finally incorporated into Circular 725.

MONTANA UNDISCOVERED NATURAL GAS RESOURCES
(Computed from U.S. Geologic Survey Data)

The U.S. Geological Survey has divided the United States into 15 regions. Montana is contained in Region 4 (as shown in Figure 3). The U.S.G.S. estimates of undiscovered recoverable resources for Region 4 were factorized to obtain a reasonable estimate of gas resources in Montana.

Table "A" contains a listing of the provinces which are totally or partially located in Montana. As seen in the Table, there are two provinces that are completely located in Montana and the other four provinces are partially located in Montana. The folded belt includes parts from Montana and Idaho. The Williston Basin is shared among Montana and North and South Dakotas. The Big Horn Basin and the Powder River Basins are mostly in Wyoming with few counties in Montana. This is clear from the accompanying map of Figure 3 and Table "A".

TABLE "A"

NORTHERN ROCKY MOUNTAIN (REGION 4) PROVINCES
FALLING IN OR INCLUDING PARTS OF MONTANA

Basin	State	County in Basin
1) Montana Folded Belt	Idaho	Boundary
		Bonner
		Kootenai
		Benewah
		Shoshone
	Montana	Lincoln
		Sanders
		Mineral
		Flathead
		Powell
		Park
		Gallatin
		Meagher
		Broadwater
		Lewis & Clark
		Missoula
		Beaverhead
		Madison
		Jefferson
		Silver Bow
		Deer Lodge
		Ravalli
		Granite
		Lake
2) Sweetgrass Arch	Montana	Glacier
		Pondera
		Teton
		Cascade
		Judith Basin
		Fergus
		Petroleum
		Phillips
		Blaine
		Hill
		Liberty
		Toole
		Chouteau
3) Central Montana	Montana	Wheatland
		Sweetgrass
		Stillwater
		Golden Valley
		Musselshell
		Treasure
		Yellowstone
		Rosebud

TABLE "A" (Con't.)

Basin	State	County in Basin
4) Williston Basin	Montana	Valley Garfield Daniels Sheridan Roosevelt McCone Richland Dawson Wibaux Prairie Fallon Carter Custer
	North Dakota	All Gas Producing Counties (total of the State)
	South Dakota	
5) Big Horn basin	Montana	Carbon
	Wyoming	Park Big Horn Hot Spings Washakie
6) Powder River Basin	Montana	Big Horn Powder River
	Wyoming	Niobrara Sheridan Johnson Campbell Crook Weston Converse

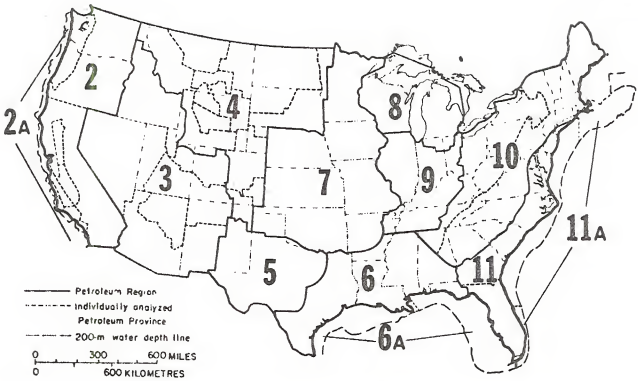


FIGURE 3 —Index map of the conterminous Lower 48 United States showing the regional boundaries:

Region 2, Pacific Coastal States;
Region 2A, Pacific Coastal States Offshore;
Region 3, Western Rocky Mountains;
Region 4, Northern Rocky Mountains;
Region 5, West Texas and Eastern New Mexico;
Region 6, Western Gulf Basin;
Region 6A, Gulf of Mexico;
Region 7, Mid-continent;
Region 8, Michigan Basin;
Region 9, Eastern Interior;
Region 10, Appalachians;
Region 11, Eastern Gulf and Atlantic Coastal Plain;
Region 11A, Atlantic Coastal States Offshore.

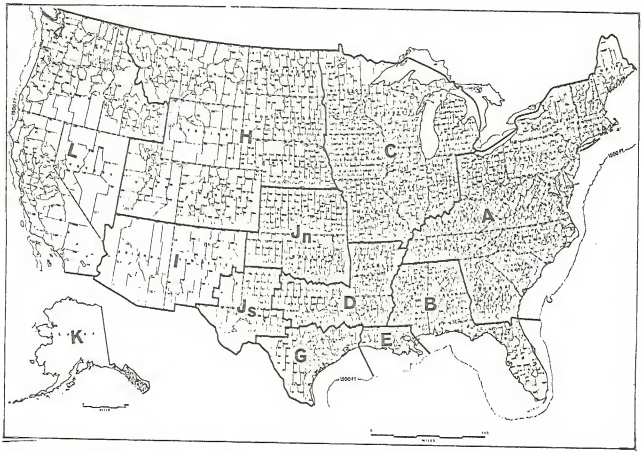


Figure 4- Publication Areas - Potential Gas Committee.

The algorithm used by R. W. Cattany[1] for disaggregating U.S.G.S. information for Colorado was adopted for breaking out Montana's resource estimates. This algorithm is a modification of the one used by the U.S.G.S. The basic assumption in this method is that past production in each county of each basin indicates the resource present. In addition to this method others have been used in this report to alleviate the bias of this method to counties in advanced stages of development.

Tables "B" and "C" show undiscovered resources of natural gas in Montana associated provinces. In Table "B", the statistical mean and the standard deviations for these basins are given. In Table "C" (provided by the U.S.G.S.), there are the following province parameters such as areas, volumes, cumulative production, measured reserves, total demonstrated reserves, and undiscovered recoverable range.

Table "D" shows the undiscovered natural gas resources for the United States onshore, Region 4, and Montana associated basins. The mean figure for the resources as well as the 95% and 5% estimated range values, are shown. The 1975 gas production by basins is given in Table "E". The percentage of Montana gas production is given in the last column. These percentage values were used in separating the resources in Montana from totals for the Basin.

Table "F" gives the estimated Montana undiscovered natural gas resources by basins. In the column of Montana percents are given the percentage of production in 1975 attributed to Montana for each basin. The total estimate of Montana undiscovered resources is 2.02 $\pm$ 0.55 trillion cubic feet. The areal percentage of each basin located in Montana was also used as a base for dividing the resources of the associated basins. The total resources using this criterion for disaggregation of the resources is shown in Table "G". The Montana total is 3.12 $\pm$ 0.61 trillion cubic feet of gas.

[1] Ronald W. Cattany - Colorado Alternative Scenarios Energy System, Appendix GL, Colorado School of Mines (1975).

TABLE "B"

UNDISCOVERED RECOVERABLE RESOURCES OF
NATURAL GAS (in Tcf)

(U.S.G.S. Estimates for Montana Associated Basins)

Basin	Mean*	Standard Deviation*
Montana Folded Belt	0.44	0.19
Sweetgrass Arch	1.09	0.48
Central Montana Uplift	0.20	0.16
Williston Basin	1.35	0.61
Big Horn Basin	2.75	0.94
Powder River Basin	2.56	0.53

*Approximated to two decimals

TABLE "C"

GAS

(In Trillion Cubic Feet)

Number	Province Name	Area (Mi^2)	Volume (Mi^3)	Cumulative Production	Demonstrated Reserves: Measured Reserves	Demonstrated Reserves: Total	Inferred Reserves	Undiscovered Recoverable: Statistical Mean	Undiscovered Recoverable: Marginal Probability	Undiscovered Recoverable: Range
Reg. 4	Northern Rocky Mountains									
29	Montana Folded Belt	13,500	27,524	0	0	0	0	0.44		0.2- 0.8
30	Sweetgrass Arch	42,650	37,071	0.329	0.591	0.92	0.465	1.09		0.5- 2.0
32	Central Montana	17,355	23,603	0.015	0.025	0.04	0.019	0.2		0.05- 0.5
33	Williston Basin	141,050	213,690	1.095	0.831	1.926	0.652	1.35		0.6- 2.6
34	Big Horn Basin	8,500	22,220	1.198	0	1.198	0	2.75		1.5- 4.5
36	Powder River Basin	30,240	53,222	0.764	0.692	1.456	0.544	2.56		1.5- 4.0

Negligible -- less than 0.001 trillion cubic feet

TABLE "D"

U.S.G.S. UNDISCOVERED RECOVERABLE RESOURCES
OF NATURAL GAS

LOCATION	NATURAL GAS (Tcf)
U.S.	
Onshore (Mean)	377
Estimated Range (95%-5%)	264-506
Region 4	
Mean	29
Estimated Range	18-47
MONTANA BASINS*	
Montana Folded Belt	
Mean	0.44
Estimated Range	0.2-0.8
Sweetgrass Arch	
Mean	1.09
Estimated Range	0.5-2.0
Central Montana Uplift	
Mean	0.2
Estimated Range	0.05-0.5
Williston Basin	
Mean	1.35
Estimated Range	0.6-2.6
Big Horn Basin	
Mean	2.75
Estimated Range	1.5-4.5
Powder River Basin	
Mean	2.56
Estimated Range	1.5-4.0

*All Montana Basins are in Region 4

TABLE "E"

BASIN	STATE	1975 GAS PRODUCTION BY STATE (MCF)	CUMULATIVE PRODUCTION	% PERCENTAGE OF CUMULATIVE
Montana Folded Belt	Montana	None	None	- - -
Sweetgrass Arch	Montana	37,201,133	37,201,133	100%
Central Montana	Montana			
Williston Basin	Montana	5,102,014	37,400,014	13.68%
	No. & So. Dakotas	32,298,000 (1)		86.35%
Big Horn Basin	Montana	1,319,453	41,550,235	3.176%
	Wyoming	40,230,782		96.82%
Powder River Basin	Montana	475,077	53,511,867	0.8877%
	Wyoming	53,036,790		99.11%

(1) USBM Preliminary Data for Mineral Yearbook

TABLE "F"

UNDISCOVERED RECOVERABLE RESOURCES
OF NATURAL GAS IN MONTANA*

Total Resources

Province	Mean	Standard Deviation	Montana %	Montana Estimated (Tcf)*
Montana Folded Belt	0.44	0.19	100	0.44 ± 0.19
Sweet Grass Arch	1.09	0.48	100	1.09 ± 0.48
Central Montana Uplift	0.20	0.16	100	0.20 ± 0.16
Williston Basin	1.35	0.61	13.68	0.18 + 0.08
Big Horn Basin	2.75	0.94	3.176	0.09 ± 0.03
Powder River Basin	2.56	0.78	0.89	0.02 ± 0.01
				2.02 ± 0.55

*1975 Gas Production was used to break out Montana's Resources in the Basins shared with other states.

The bases for these estimates are the data from U.S.G.S. Circular 725.

TABLE "G"

UNDISCOVERED RECOVERABLE RESOURCES
OF NATURAL GAS IN MONTANA*

Province	Mean	Standard Deviation	Montana % (Area)	Montana Estimated (Tcf)
Montana Folded Belt**	0.44	0.19	100	0.44 ± 0.19
Sweetgrass Arch	1.09	0.48	100	1.09 ± 0.48
Central Montana Uplift	0.20	0.16	100	0.20 ± 0.16
Williston Basin	1.35	0.61	18	0.24 ± 0.11
Big Horn Basin	2.75	0.94	13	0.36 ± 0.12
Powder River Basin	2.56	0.78	31	0.79 ± 0.24
		Montana Total	=	3.12 ± 0.61

*Calculations based on the percentage area of the basin located in Montana.

**Idaho portion of this province is mostly batholith and was excluded as possible hydrocarbon province.

THE POTENTIAL GAS COMMITTEE METHODOLOGY

The following is a copy of the techniques for estimating potential supply of natural gas as given in the Potential Gas Committee Publications.

1. BASIC APPROACH

The basic technique for estimating potential gas supply is to compare the factors that control known occurrences of gas with factors present in prospective areas. Known occurrences are expressed as the volume of natural gas ultimately recoverable per unit volume of reservoir rock within an adequately explored portion of a geologic province. Such known relationship, with appropriate adjustment for variations in geological and reservoir conditions, is then attributed to incompletely explored sedimentary rocks in the same or in a similar geologic province.

A general outline of the attribution technique for estimating potential supply of natural gas follows.

FOR PRODUCTIVE FORMATIONS

a. Within a productive provinee or sub-province estimate the volume of
   (1) productive gas-bearing rock, and
   (2) potential gas-bearing rock:
      (a) associated with existing fields for estimating Probable Potential Supply, and
      (b) associated with productive formations for estimating Possible Potential Supply.
b. Add cumulative production and proved reserves to obtain the total volume of ultimate recoverable gas for the adequately explored portion of the productive gas-bearing rocks.
c. Divide this figure by the volume of adequately explored productive gas-bearing rocks to obtain the ultimate recoverable gas per unit volume of productive rocks.
d. Adjust the unit volume figure for variations in geological and reservoir conditions in the Probable and Possible gas-bearing rocks.
e. Using these adjusted figures:
   (1) Estimate *Probable Potential Supply* in extensions and new pools associated with existing fields.
   (2) Estimate *Possible Potential Supply* by applying these adjusted figures to the wildcat traps and structures estimated to be present in the inadequately tested portion of the province or sub-province.

FOR NON-PRODUCTIVE FORMATIONS AND NON-PRODUCTIVE PROVINCES

a. Estimate the volume of untested sediments in non-productive provinces and the volume of potential but non-productive sediments in productive provinces.
   (1) Estimate the *Speculative Potential Supply* in these sediments by comparing them with similar sediments in other provinces or sub-provinces where their productive characteristics are known.

2. THE ROLE OF JUDGMENT IN ESTIMATING POTENTIAL SUPPLY

In proceeding from the known to the unknown, the judgment of the estimator is the most significant factor in making estimates of potential supply, particularly in the categories of *Possible* and *Speculative* supply. The appropriate adjustments referred to in Section 1 above are direct reflections of the estimator's judgment. Only the estimator has the detailed knowledge and the experience necessary to select appropriate adjustments for the geological provinces for which he is responsible. In all respects, the estimates of potential supply by the Potential Gas Committee reflect an objective, scientific approach to the problem. An attempt is made to use all pertinent geological and engineering data.

3. LIMITING CONSIDERATIONS IN MAKING ESTIMATES

At the present, no potential supply of gas is considered at depths greater than 30,000 feet or in offshore areas, where water depths are in excess of 1,500 feet.

Economic, technological and governmental policy considerations in estimating potential supply also impose restrictions, and to that extent they are considered limitations of the estimates. Such limitations are indicated in Section 4, which follows.

4. ECONOMIC AND TECHNOLOGICAL ASPECTS OF ESTIMATING POTENTIAL SUPPLY

Economic, technological and governmental policy considerations that are taken into account in the Potential Gas Committee's estimate of

potential gas supply are related to (1) past production and proved reserves of natural gas, and (2) all wells which would be drilled in the future under the assumed conditions that there will be adequate but reasonable prices for gas and oil and normal improvements in technology.

Fundamental economic considerations — which include but are not limited to prices, costs, rates of take, recovery factors, abandonment pressures, etc. — are inherent in the definition of proved reserves: ". . . recoverable in the future from known oil and gas reservoirs under existing economic and operating conditions." Some gas that is actually present in known reservoirs is not producible because of the relationship between costs and prices, and therefore is not included in recoverable reserves. Furthermore, there are other known gas accumulations of such small size that none of the gas can be produced in commercial quantities under ". . . existing economic and operating conditions." Such considerations result in proved reserves being something less than the total volumes of gas existing in known reservoirs. These same limitations are applicable to the estimates of potential supply. If a fundamental change in economics or technology occurs, estimates of potential supply will be changed accordingly.

The attribution technique presented in Section I describes relationships for known occurrences of ultimately recoverable volumes of gas to prospective gas accumulations, after appropriate adjustment for variations in geological and reservoir conditions are made. The explicit assumption of adequate but reasonable prices and normal improvements in technology in the definition of potential supply relates to improvements in exploration and production techniques. Adequate prices, normal technological improvements and reasonable governmental policies are required to bring about the drilling necessary to prove the potential supply. These assumed conditions permit estimates of potential supply to be made by the Potential Gas Committee on the basis of relevant past history and experience concerning recovery factors, as well as the size and type of reservoirs which have been found, developed, and produced, without speculating as to future levels of prices and costs.

POTENTIAL SUPPLY OF NATURAL GAS

IN MONTANA

Information for this section was obtained from Mr. Robert B. Rhodes, Montana Power Company. The guidelines for the estimation of potential supply of natural gas are given in the publications of the potential gas committee. A copy of the guideline is enclosed.

The study of the potential supply and future requirements is established by the industry in cooperation with the Colorado School of Mines. The Gas Industry Committee (AGA, API, and INGAA) is for financing and industry liaison. The Potential Gas Agency of the Colorado School of Mines and Mineral Resources has as its objectives the maintenance of standards, approval of criteria and methods, insurance of objectivity and the evaluation of reports of estimates of potential gas.

The Potential Gas Committee outlines the study, establishes criteria and methods, designates and instructs work committees, supervises, coordinates and compiles estimates made by work committees. To insure unbiased objectivity and scientific standards the Gas Industry Committee takes no part in the work or deliberation of the Potential Gas Committee or its work committees.

Table "H" gives the estimated Montana values for potential gas supply as determined by the Potential Gas Committee. The total potential gas is 5.6 trillion cubic feet. This figure is higher than those obtained for undiscovered natural gas resources derived from U.S.G.S. data. However, it may be noticed that the cumulative amount of probable and possible potential gas (2.1 Tcf) is very close to the mean value (2.02 Tcf) calculated using U.S.G.S. data and 1975 production rates. The value of 5.6 Tcf of gas for the total potential gas supply is still less than the 7.06 trillion cubic feet estimated by the Steering Committee.

TABLE "H"

POTENTIAL SUPPLY OF NATURAL GAS

IN MONTANA (Tcf)

(Potential Gas Committee Data)

Category	Montana Estimated Value	Area H Northern Rocky Mountains
Probable	2.1	13
Possible		26
Speculative	3.5	20
Total	5.6	59

STEERING COMMITTEE ESTIMATE

NATURAL GAS RESOURCES

Table I is an estimate of the undiscovered natural gas resources of Montana as estimated by the project Steering Committee. It may be noticed that the serious difference in this Table with other estimates is in the figure of the Montana Folded Belt. Due to the importance and magnitude of the difference, further discussion of this subject is given under separate title about the Montana Overthrust Belt. The estimates for the other Montana provinces are close to the estimates by the U.S.G.S. Resource Appraisal Group and those by Potential Gas Committee.

TABLE "I"

MONTANA UNDISCOVERED RECOVERABLE RESOURCES
OF NATURAL GAS*

(Estimates of the Project Steering Committee)

Province	Montana Estimated (Tcf)	%
Montana Folded Belt	5.00	70.82
Sweetgrass Arch	1.00	14.17
Central Montana Unlift	0.20	2.83
Williston Basin	0.36	5.10
Big Horn Basin	0.25	3.54
Powder River Basin	0.25	3.54
Total	7.06	100.00

*Estimates of the Steering Committee

PROVED RESERVES OF NATURAL GAS

The proved reserves of natural gas aa reported by the American Gas Association are given in Table J. The Table shows the figures for Montana and for United States proved reserves. We may notice that the U.S. proved reserves had been on a steady decline since 1967 with the exception of 1970 when Alaska's North slope reserves had been added. Fortunately, in comparison Montana reserves do not show the same definite trend of decline. The proved reserves in Montana showed 3.22% increase in 1975. We expect that this increasing may be sustained for some time if healthy industrial conditions prevail. In Figure 7 the proved reserves of Montana as well as percent change from previous year is illustrated.

TABLE "J"

PERCENT CHANGE IN PROVED RESERVE BASE
NATURAL GAS

	Montana		U.S.	
Year	Proved Reserves Billion C.F.	Percent Change From Previous Period	Proved Reserves Billion C.F.	Percent Change From Previous Period
1966	620		289,333	
		+35.16		+1.24
1967	838		292,908	
		+ 8.83		-1.90
1968	912		287,350	
		+21.71		-4.26
1969	1,110		275,109	
		- 0.90		+5.68
1970	1,100		290,746	
		- 6.82		-4.11
1971	1,025		278,806	
		+ 3.80		-4.56
1972	1,064		266,085	
		+ 2.54		-6.06
1973	1,092		249,950	
		-21.20		-5.13
1974	901		237,132	
		+ 3.22		-3.77
1975	930		228,200	

TABLE "K"

ANNUAL ESTIMATES OF PROVED NATURAL GAS RESERVES
1966-1975

Total All Types[2]

Year	MONTANA[3] Billion Cubic Feet[5]	MONTANA[3] 10^{15} BTU	U.S.[4] Billion Cubic Feet	U.S.[4] 10^{15} BTU
1966[6]	620	.620	289,333	289.333
1967	838	.838	292,908	292.908
1968	912	.912	287,350	287.350
1969	1,110	1.110	275,109	275.109
1970	1,100	1,100	290,746	290.746
1971	1,025	1.025	278,806	278.806
1972	1,064	1.064	266,085	266.085
1973	1,092	1.092	249,950	249.950
1974	901	0.901	237,132	237.132
1975	930	0.930	228,200	228.200

(1) American Gas Association, "Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas in the United States and Canada and United States productive capacity as of December 31, 1974" - Volume 29, May 1975

(2) Includes non-associated, associated-dissolved and underground storage

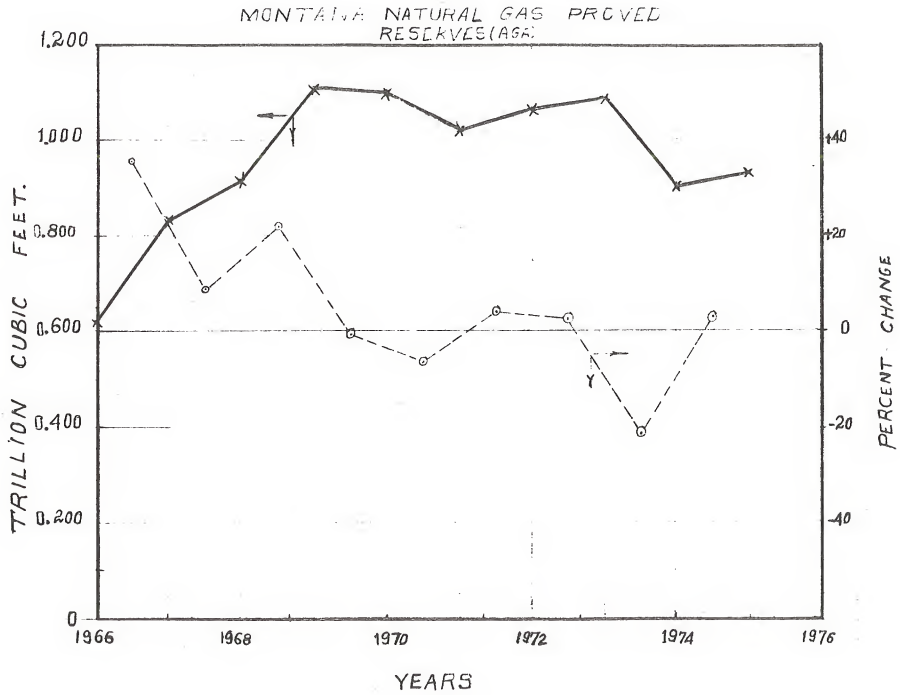
(3) Table XIII - 20, Page 141 in the above given reference 1

(4) Table VII, Page 120 in the above given reference 1

(5) At 14.73 psia, at 60° F

(6) As of December 31 of year indicated

FIGURE 7


MONTANA NATURAL GAS PROVED RESERVES (AGA)
1.200
1.000
0.800
0.600
0.400
0.200
0
TRILLION CUBIC FEET.
+40
+20
0
-20
-40
PERCENT CHANGE
1966
1968
1970
1972
1974
1976
YEARS

CUMULATIVE IDENTIFIED NATURAL GAS RESERVES AND UNDISCOVERED RECOVERABLE RESOURCES

In Table "L", column (2) shows measured reserves of natural gas in Montana. The total value is 0.901 trillion cubic feet which is the approved reserves given by AGA as of December 31, 1974. Column (4) shows a figure of 0.59 trillion cubic feet as the inferred reserves of gas in Montana.

The total of the proved and inferred reserves, plus the undiscovered recoverable resources, is 3.51 $\pm$ 0.55 trillion cubic feet, and is considered by the author the most realistic figure for natural reserves and resources of Montana as of December, 1974.

TABLE "L"

MONTANA'S ASSOCIATED BASINS
CUMULATIVE IDENTIFIED NATURAL GAS RESERVES
AND UNDISCOVERED RECOVERABLE RESOURCES (Tcf)

(Based on U.S. Geological Survey Data)

(1) Province Name	(2) Measured Reserves	(3) Montana %**	(4) Inferred Reserves	(5) = (2) + (4)	(6) Undiscovered Recoverable Statistical Mean
Montana Folded Belt	0	100	0	0	0.44 ± 0.19
Sweet Grass Arch	0.591	100	0.47	1.06	1.09 ± 0.48
Central Montana	0.025	100	0.02	0.045	0.20 ± 0.16
Williston Basin)		13.7	0.09	(	0.18 ± 0.08
)				(	
Big Horn Basin)	0.285*	3.2	0	(0.385	0.09 ± 0.03
)				(	
Powder River Basin)		0.9	0.01	(	0.02 ± 0.01
Totals	0.901		0.59	1.49	2.02 ± 0.55

Cumulative **Identified** Reserves and Undiscovered Recoverable Resources (Total(5) + Total (6)

= 3.51 ± 0.55

*Calculated from proved reserves for 1974 given by AGA

**Using 1975 production figures as basis of division of resources

CONCLUSIONS

From the previous study, it is possible to summarize the following conclusions:

1. The amount of recoverable natural gas reserves and resources of Montana are in the range of 3 - 7 trillion cubic feet.

2. The reserves and resources of natural gas in Montana would be sufficient if developed to provide local consumption in the range of 37-87 years at the 1974 rate of consumption.

3. Development of the above resources could guarantee Montana natural gas self-sufficiency at least for the next twenty years.

4. The present trend of de-regulation of natural gas prices and leasing in the speculative areas would put the natural gas industry in Montana in a position to increase gas production and alleviate shortages.

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APPENDIX

COMMENTS ON MONTANA FOLDED BELT

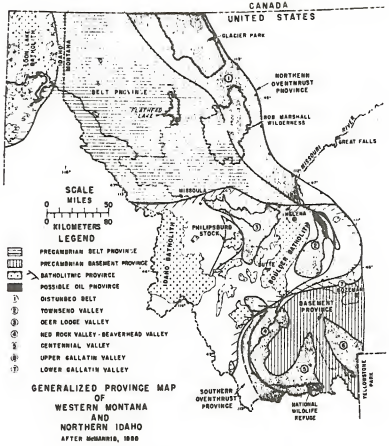


FIGURE 8 - MONTANA FOLDED BELT

COMMENTS ON MONTANA FOLDED BELT
(W. MONTANA & N. IDAHO)

Only the Montana section of this province has a potential capacity of producing hydrocarbons. Most of the Montana area is eroded down to the Precambrian surface. The Montana Folded Belt can be divided into two sections, north and south (see map). The northern section, which is northwest Montana, is in most parts the Precambrian belt province, flanged to the east, northeast by the Northern Overthrust Belt. The Overthrust Belt appears to be the only part capable of producing hydrocarbons in this area. The presence of good structual traps though is not associated with the presence of good source beds.

The southern section of the folded belt, which is southwestern Montana, is characterized by the existence of six structual basins. The three extreme southwest basins - Red Rock Valley, Beaver Head Valley and Centenial Valley - are Montan's most prospective for hydrocarbons with strata about 20,000 feet deep. The other three basins have less hydrocarbon potential. These are Townsend Valley, Deer Lodge Valley and Upper Gallatin Valley. The basins so far are practically untested. The Farmers Union Central Exchange drilled a well to 15,772 feet in Beaver Head County, Montana. The well penetrated through a thrust fault at 13,000 feet and went from Pennsylvanian back into Cretaceous rocks, and was abandoned as a dry hole, apparently short of the objective. The small potential in the basins, high exploration costs, and complex geology were the factors hindering development of the area. The gas price increases will render the area more economically attractive.

Although the Disturbed Montana Belt has been illusive to the oil companies for more than 70 years, it still has the higher priority in potential hydrocarbon accumulation. The comparison between the Disturbed Belt and the Canadian Foothills of similar structure led the Steering Committee to estimate a figure of five trillion cubic feet of gas undiscovered in the Montana Folded Belt. These similarities are argued by other geologists. Following is a quotation from J. L. Cannon, Jr., assessment to hydrocarbon potentials in the Northern Overthrust belt:*

"The Montana Disturbed belt has been an expensive disappointment for oil companies for nearly 70 years. Exploration has been conducted nearly continuously, at a low level, for most of that time. In the decade 1950-1960, major oil companies made a concerted effort to find commercial hydrocarbon accumulators and failed. Activity today is again at a low level."

"Primary objectives have been the unexposed updip edges of Madison thrust plates along the eastern edge of the mountain front. Seismic mapping and drilling along east border of Glacier National Park have defined few, if any, Madison thrust sheets that extend significantly eastward beyond the park boundary in the United States, Farther south along the east front of the Sawtooth Range, several wildcats have tested buried Madison thrust sheets in a very narrow strip, a mile or two wide, just east of the first Madison surface exposures. South of the Sawtooth Range in the vicinity of the Missouri River, intensely deformed Mezozoic clastic rocks confirm that

*AA PG, Memoir 15, 1971, page 560

compression and thrusting are still the dominant tectonic features. The few dry holes in this area have not been encouraging. Present seismic techniques are believed to be capable of providing adequate structual definition and many of the dry holes appear to have been favorably located."

"By comparison, similar structures in the Canadian Thrust Belt have yielded large volumes of oil and gas, demonstrating that these Laramide structures can contain hydrocarbons. One obvious difference between the two areas is in lithology of the Mississippian rocks. The black shale and dark argillaceous carbonate rocks of the lower part of the Mississippian sequence in Canada are essentially absent in northern Montana, where the entire Mississippian carbonate sequence is relatively free of argillaceous and organic material. Possibly the Mississippian rocks in northern Montana, were or are, incapable of generating sizable volumes of oil or gas."

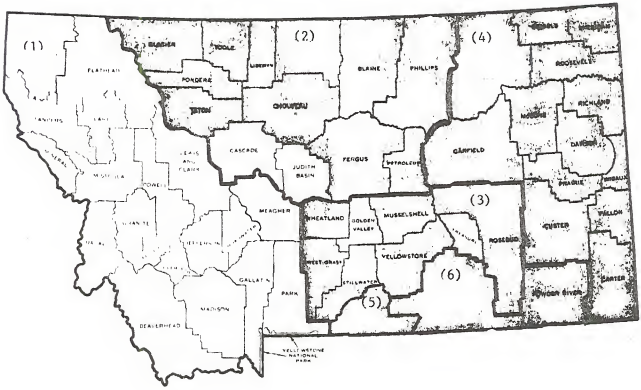
"In general, Paleozoic source beds appear to be absent in northern Montana. Cambrian, Devonian, and Mississippian lithofacies seem to be organically impoverished except for minor amounts of Mississippian black shale. Mesozoic source beds may be present in the form of dark marine shale in the Colorado group. Stebinger (1918) reported that live oil is present in the dark fractured limestone beds of the Greenhorn Formation (Colorado Group), where it is trapped by secondary Calcite cementation."

"In the near future, primary industry objective, i.e., the testing of Paleozoic thrust sheets will remain essentially unchanged. Ultimately, however, attempts undoubtedly will be made to locate fault traps further west beneath the Overthrust Belt rocks (Precambrian) as in British Columbia (Bally et al, 1966). One of the most severe obstacles to overcome is the nearly complete absence of roads west of the mountain front. In Glacier National Park and the Bob Marshall Wilderness Area (Fig. 8), oil well drilling, the ultimate exploration toole is prohibited."

Factors that appear to diminish the hydrocarbon potential of the area are: (1) Exposure of source and reservoir rocks in the Sawtooth Range, essentially excluding that area from possible production. (2) The apparent absence of good source rocks in addition to previously mentioned factors such as road network and drilling in Glacier National Park and the Bob Marshall Wilderness Areas.

"The hydrocarbon potential of the Ovethrust province in northern Montana surely cannot be rated as very good in view of the lack of a single producing field after 70 years of exploration. Yet the area is sufficiently large enough to contain millions of barrels of oil or equivalent volumes of gas, and drilling density is low."

Intensive seismic exploration and selected testing wells will get the estimation of the resources of Montana Folded Belt out of dead center to a more precise estimate, narrowing down the range of estimates which is as low as 0.25 Tcf and as high as five trillion cubic feet.


(1)
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FLATHEAD
LAKE
LINCOLN
SANDERS
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